10/511337

Rec'd PCT/PTO 15 OCT 2004

METHOD OF CONTROLLING LUBRICANT PROPERTIES BY MEANS OF DILUTING THE SAME

The present invention relates to a process for simultaneously controlling two or more properties of a lubricant or working fluid which lubricant or working fluid is suitable for use in a system which is subject to

5   a range of operating conditions. The invention further relates to apparatus for carrying out said process.

The properties of lubricating fluids vary with changes in the conditions under which they are utilised. For example, the viscosity of a lubricant increases as

10   the temperature of the lubricant decreases. This presents difficulties in designing lubricating systems which provide effective, if not optimum, lubrication over a range of operating temperatures. A lubricant with an optimal viscosity at a high operating temperature may be

15   far too viscous to permit a machine to operate safely in, or even to be started from, cold or low ambient conditions. In response to this problem, lubricating systems utilising multiple phases of lubricants have been proposed, for example in International Publication No.

20   WO-A-96/11244.

However, more than one property of a lubricant or working fluid may vary as conditions under which the lubricant or working fluid is utilised vary. For example, as the temperature of a lubricant or working

25   fluid varies, its viscosity, density, pressure response of viscosity, compressibility and the propensity of the viscosity to change with shear rate, all vary. The lubricant film thickness in a particular contact will also vary with temperature. In many cases, one desirable

property may be inconveniently inextricably linked to a large temperature dependence of another property.

In traction drives, power and torque are transmitted between machine elements having smooth surfaces through fluids or lubricants sometimes called "traction fluids". For example, traction fluids enable one smooth rotating wheel to drive another smooth wheel that is pressed against it, like gears without teeth. The motion is a mixture of rolling and sliding. The traction coefficient is the ratio of the tangential force to the normal force. The normal force is the force that presses the two surfaces together. The higher the traction coefficient, the more effectively the device can transmit power. Therefore, it is desirable that the lubricant that is applied to reduce wear by separating the metal surfaces possesses as high a coefficient of traction (also called friction) as possible under all conditions in which the traction drive operates. The improved performance associated with a higher traction coefficient could be exploited, for example, by making the device smaller and lighter. However, the traction coefficient of a traction fluid usually varies with temperature, e.g. the traction coefficient under cold start up conditions may be different to that under warm operating conditions. This has the result that devices, such as transmissions for vehicles, cannot be designed to exploit the highest values of traction coefficient.

Furthermore, fluids that possess high traction (i.e. a high traction coefficient) at a particular temperature tend to exhibit a large variation of viscosity with temperature as the temperature changes through that point. To transmit force, the viscosity of the traction fluid must rise to high values as it is subjected to the

high pressure in the load-bearing zone between the metal
surfaces. However, a rapid increase in viscosity with
pressure is usually associated with a rapid change in
viscosity (i.e. low-shear ambient pressure dynamic
viscosity) with temperature. Conversely fluids which
have a viscosity that changes little with temperature,
have a low pressure coefficient of viscosity and, most
probably, have a low traction coefficient. Therefore, in
selecting a traction fluid, the designer is forced to
compromise the value of the traction coefficient so that
the fluid will be of a low enough viscosity at low
temperatures to be able to operate. A fluid having a
high traction coefficient (e.g. 0.095 or above, measured
at a slide-to-roll ratio (SRR) of 2.2 % with a pressure
in the contact of 1.125 GPa) at operating temperatures
such as 110 °C, will become unacceptably viscous at lower
temperatures, in particular at the cold start-up
temperatures that are commonly encountered during winter
even in temperate climates. Typically, a lubricant
formulated to keep its viscosity low enough for easy cold
starting will possess a traction coefficient at warmed up
operating conditions well below the maximum traction
coefficient that has been observed in any fluid, of
approximately 0.118. Currently the best compromises of
traction fluids offer high viscosity at low temperatures
and moderate traction at warmer operating temperatures.

      There remains a need for a traction fluid which
possesses a high traction coefficient over the entire
temperature range within which the traction fluid must
operate and which traction fluid has an effective
viscosity over the same temperature range. Such a
traction fluid would be of particular benefit for
infinitely variable transmissions.

A similar conflict between the properties required
at warm operating conditions and those required to permit
start up under cold conditions is found for working
fluids such as hydraulic fluids for large construction
5   equipment for use, e.g., in severe climates. In such
climates start-up temperatures can be as low as -40°C and
warm operating temperatures can be up to 95°C. For
hydraulic fluids, properties such as viscosity,
compressibility and the pressure response of viscosity
10   are important for effective system operation. An ideal
hydraulic fluid, for example, might have a low
compressibility in combination with pressure- and
temperature- independent viscosity. Such a fluid cannot
be achieved in practice. Low compressibility is
15   associated with a rapid increase in viscosity with
pressure and a strong dependence of viscosity on
temperature. To deal with this conflict in properties in
hydraulic fluids, operators may resort to "exercising"
unloaded hydraulic equipment for an hour before starting
20   productive work in very cold conditions. This is clearly
an expensive and unsatisfactory solution to the problem.
       Even in temperate climates the temperature of the
hydraulic oil may change by 60 to 80°C from its starting
temperature to the warm operating temperature, in a
25   hydraulic circuit subjected to continuous or heavy usage.
The change in viscosity that is a consequence of this
temperature change, alters the mechanical and volumetric
efficiencies of the hydraulic system. In this context,
the mechanical efficiency is a measure of the work
30   required to pump the fluid around the circuit. The
volumetric efficiency is a measure of the internal
leakage of high pressure fluid past the sliding seals of

the actuators. The increase in internal leakage as the
viscosity decreases with increasing temperature, may
reduce the force that that the hydraulic actuators can
apply. An effective balance of mechanical and volumetric
efficiencies cannot be maintained across the temperature
range.

There remains a need for a hydraulic fluid whose
viscosity remains constant within certain limits over the
entire temperature range at which the fluid must operate,
and which fluid simultaneously possesses a low
compressibility and an effective pressure response of
viscosity.

The present invention solves the above-mentioned
problems by providing a process by which two or more
properties of a lubricant or working fluid can be
maintained at optimal or effective values over a range of
system operating conditions.

Thus, the present invention provides a process for
controlling two or more properties of a lubricant or
working fluid which lubricant or working fluid is
suitable for use in a system in which operating
conditions change which process comprises:

(i)   providing a base fluid in which the two or more
      properties are optimal for "warm" operating
      conditions;

(ii) providing a diluent which is miscible with said
      base fluid under all system operating conditions;
      and

(iii) reversibly diluting said base fluid with the
      diluent in response to change in system operating
      conditions.

It has surprisingly been found that, by choosing the

base fluid and diluent according to specific criteria,
two or more properties of a lubricant or working fluid
can be simultaneously controlled by reversible dilution
of the base fluid in response to variations in the
operating conditions under which the lubricant or working
fluid is used.

The systems to which the process of the present
invention applies include systems which comprise moving
components that require lubrication. Such systems may be
engines or automobile transmissions that have moving
components that require traction fluids. Examples of
such moving or operating components are gears, bearings,
clutches and traction drive variators. The process of
the present invention also applies to hydraulic systems
that are actuated by working fluids such as hydraulic
fluids under pressure. Examples of moving components in
hydraulic systems are actuators. The lubricant of the
present invention may have a general lubricating function
or it may have other functions such as torque
transmission as in traction fluids. The working fluid of
the present invention may be a lubricant that can be used
as an hydraulic fluid.

In one aspect of the present invention there is
provided a process for lubricating a system in which
operating conditions change which process comprises:
(i)   controlling two or more properties of a lubricant;
       and
(ii) applying the resultant lubricant to the system.

In another aspect of the present invention there is
provided a process for providing a working fluid for a
system in which operating conditions change which process
comprises:

(i)   controlling two or more properties of the working
      fluid; and

(ii) applying the resultant working fluid to the system.

By applying the resultant lubricant and/or working
fluid to the system includes bringing it into contact
with a moving or operating component of the system.

The properties to be controlled depend on the nature
of the task that the lubricant or the working fluid is
required to perform in a particular type of machine.
Preferably, one of the properties is viscosity as this is
a key property for most lubricants and working fluids.
By viscosity is meant the low-shear ambient pressure
dynamic viscosity. In, e.g. a hydraulic fluid, the
compressibility and/or the pressure response of viscosity
and/or the lubricating film thickness may be controlled.
In, e.g. a traction fluid, the traction coefficient may
be controlled. In a preferred embodiment, the process of
the present invention controls the viscosity in addition
to one or more other property (properties) of a lubricant
or working fluid for use in a system in which operating
conditions are subject to change. In a more preferred
embodiment, the process of the present invention controls
two properties of the lubricating or working fluid.

In the process of the present invention, two or more
properties of the lubricant or working fluid are
controlled. By "controlled" is meant that the properties
in question are maintained at values which are effective
for system operation and are preferably optimal for
system operation. The acceptable variation of the value
of each property from the optimal "warm" operating
conditions value will depend on the property in question.
For example, the value of viscosity may increase by 300%

from its optimised value and still the lubricant/working fluid will perform effectively.

In a traction fluid, preferably the value of traction coefficient is controlled to within +/-30 % of its optimised value, more preferably to within +/- 15% of its optimised value.

In the process of the present invention, the base fluid is specifically selected so that the two or more properties are optimal for "warm" operating conditions. By "optimal" is meant that the two or more properties of a particular composition of base fluid are such that the system performs better with respect to at least one, and preferably both, of these properties at "warm" operating temperatures than at cold start up or ambient operating temperatures.

For example, the base fluid may be a traction fluid which has a high coefficient of traction and low viscosity at "warm" operating temperatures but has a low coefficient of traction and high viscosity under cold start up conditions.

"Warm" operating conditions are conditions under which the system is at a temperature greater than that under cold start-up or ambient conditions. Cold start up conditions can give rise to temperatures in the range of -40°C to 25°C, depending on the climate. "Warm" operating conditions include operating conditions at which the system spends most of its working time, e.g. the working temperature of a machine. "Warm" operating conditions can include a range of temperatures up to the highest operating temperature of the system and may include different operating conditions of different components in the system. Typically for automotive traction drives this range is from 90°C to 150°C. In

large items of hydraulic equipment under warm operating
conditions the temperature of the working fluid can be in
the range of 50 to 95°C.

In a preferred embodiment, the base fluid has a high
traction coefficient and a low viscosity at "warm"
operating temperatures. Preferably the base fluid has
traction coefficient measured at 2.2% SRR under a load of
1.125 GPa, of greater than 0.08 at temperatures between
90 and 150 °C and a viscosity of less than 100 mPas over
the same temperature range. Suitable high traction
fluids may contain a high proportion of saturated rings
linked by short chains or fused in pairs or larger
clusters. Said fluids may be conveniently obtained
synthetically or by refinery processing of crude oil.
Base fluids may be hydrocarbons or esters or contain
ether or carbonate groups. Certain commercially
available products such as that available under the trade
designation "Techtrac M73" ex. Tekchem Corporation,
Tokyo, Japan, contain mixtures of molecules that result
from the hydrogenation of dimers and trimers of α-methyl
styrene. The molecules typically consist of two or three
cyclohexyl rings connected by short methyl-branched alkyl
chains. Further higher-boiling components may also be
present. These components may include structures
containing condensed rings. Suitable base fluids can be
prepared from these products by varying the proportion of
dimers relative to that of higher-boiling components in
the mixture. Varying the proportion of dimers to higher-
boiling components varies the temperature at which the
resulting fluid has its maximum traction coefficient.
Thus, in one embodiment of the present invention, the
proportion of dimers is selected so as to provide a base

fluid with a maximum coefficient of traction at a
particular temperature, i.e, the base fluid is custom-
designed for a particular temperature range of "warm"
operating conditions. Preferably, the base fluid
comprises a mixture of dimers and trimers (including the
condensed ring structures). Said base fluid generally
comprises from 5 to 80 wt. %, preferably from 5 to 50 wt.
% and more preferably from 10 to 30 wt. % of dimers,
based on the total weight of the base fluid. The
proportions are measured using gas chromatography with
flame-ionisation detection.

The present invention provides a lubricant in which
the traction and the viscosity of the lubricant can be
maintained within narrow ranges over the entire
temperature range that the traction drive operates from
the coldest start to the peak operating temperature.
Such constancy of properties cannot be achieved in a
single fluid of unchanging composition. Hitherto it has
been believed that the property of high traction
exhibited by certain fluids under some conditions is a
narrow and specific consequence of their composition and
that the property of high traction would be lost on
admixture of another fluid into the traction fluid.
However, it has now been found that by choosing the base
fluid and diluent according to specific criteria, the
property of high traction possessed by the base fluid at
one temperature can be maintained or nearly maintained at
other temperatures by reversibly diluting the base fluid
with the second fluid in specific ratios that depend upon
the temperature. In this way two properties that are
important in traction fluids, namely the viscosity and
the traction coefficient, may be both maintained close to
optimum values over a very wide temperature range (for

example, 150°C) using this technique of reversible
dilution.

The diluent and the base fluid are selected so that
they are miscible under all operating conditions. By
miscible is meant that the diluent and base fluid
dissolve when brought together and form one phase. "All
operating conditions" includes cold start up or ambient
conditions and "warm" operating conditions. The present
invention therefore provides a single phase lubricating
system suitable for use in a system in which operating
conditions change. This provides significant advantages
over the multiphase lubricating processes of the prior
art.

Suitably the base fluid has a higher viscosity and a
lower volatility than the diluent. In the case of the
traction drive, the base fluid will typically have a
viscosity greater than 5 mPas at 100°C and the diluent
will typically have a viscosity below 1 mPas at 100 °C
and below 10 mPas at 0°C.

Suitable diluents will possess a low viscosity
especially at temperatures below 0°C. The lower the
viscosity of the diluent, the less is required to
decrease the viscosity of the base fluid mixture.
Suitably, the diluent has a melting range below -40°C and
a melting point below -50°C. The boiling range of the
diluent should be low enough to enable it to be removed
by evaporation from the mixture either at ambient or at
reduced pressure. Examples of suitable diluents are
decalin which is a mixture of cis- and trans- isomers of
decahydronaphthalene and the solvent commercially
available ex. Shell Chemicals in the USA under the trade
designation "CYPAR-9", which predominantly contains

methyl-substituted cyclohexanes with 9 carbon atoms. The
diluent may also be a fuel such as gasoline or diesel.

Liquid hydrocarbon fuel oils of the gasoline boiling
range are typically mixtures of hydrocarbons boiling in
the temperature range from about 25°C to about 232°C,
comprising mixtures of saturated hydrocarbons, olefinic
hydrocarbons and aromatic hydrocarbons.

The base fuel oil is derived from straight run
gasoline, polymer gasoline, natural gasoline, dimer and
trimerized olefins, synthetically produced aromatic
hydrocarbon mixtures, from thermally or catalytically
reformed hydrocarbons, or from catalytically cracked or
thermally cracked petroleum stocks, and mixtures of
these.

The hydrocarbon composition and octane level of the
base fuel are not critical. The octane level, (R+M)/2,
will generally be above about 85 (where R is Research
Octane Number and M is Motor Octane Number).

Liquid hydrocarbon fuel oils which are middle
distillate fuel oils typically have a boiling range in
the range 100°C to 500°C, e.g. 150°C to 400°C.
Petroleum-derived fuel oils may comprise atmospheric
distillate or vacuum distillate, or cracked gas oil or a
blend in any proportion of straight run and thermally
and/or catalytically cracked distillates. Such fuel oils
include kerosine, jet fuels, diesel fuels, heating oils
and heavy fuel oils.

Diesel fuels typically have initial distillation
temperature about 160°C and final distillation
temperature of 290-360°C, depending on fuel grade and
use.

In a preferred embodiment, the diluent may comprise
a mixture of hydrocarbons and/or organic esters having a

boiling range within the range of from 50 to 200°C.

In another preferred embodiment of the present invention, a hydraulic fluid has an effective pressure response of viscosity over the entire temperature range that a hydraulic fluid must typically operate and which hydraulic fluid has an effective viscosity over the same temperature range.

Accordingly, the present invention provides a working fluid composition suitable for use in hydraulic systems which comprises a diluent and a base fluid which comprises glycerol and one or more additional components selected from alkylene glycols and/or polyoxyalkylene glycols.

The present invention also provides the use of said working fluid composition in a hydraulic system.

The diluent may be conveniently selected from water, hydrocarbons and hydrocarbon mixtures, alcohols, esters and ketones. Water is particularly preferred as a diluent.

Alkylene glycols that may be conveniently used include ethylene glycol and propylene glycol. Propylene glycol is particularly preferred.

The polyoxyalkylene glycols may be end-capped, non-end-capped or hemi-ether poly(oxyalkylene) alcohols produced by the addition of lower alkylene oxides, such as ethylene oxide, propylene oxide, the butylene oxides, or the pentylene oxides to an active hydrogen compound under polymerization conditions.

Methods of production and properties of these polymers are disclosed in US-A-2841479 and US-A-2782240 and Kirk-Othmer's "Encyclopedia of Chemical Technology", 2nd Ed., Volume 19, p. 553.

Block copolymers and random copolymers may be prepared by contacting the active hydrogen compound with a mixture of alkylene oxides, such as a mixture of ethylene and propylene or propylene and butylene oxides.

In a preferred embodiment, the polyoxyalkylene glycol that may be conveniently used in the fluid composition of the present invention is of the general formula (I)

$$R^1O-[(R^2O)_m (R^3O)_n]-R^4 \qquad (I)$$
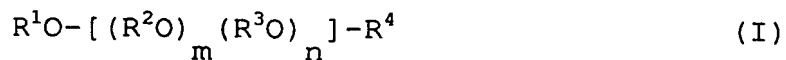
wherein R^1 and R^4 are each, independently, alkyl, aryl, alkylaryl, aryloxy, alkoxy, alkylaryloxy or hydrogen; R^2 is $-CH_2-CH_2$ and R^3 is $-CH(CH_3)-CH_2-$ and/or $-CH_2-CH(CH_3)-$, and m and n represent average numbers of R^2O and R^3O moieties in each polyoxyalkylene glycol such that m/(m+n) is in the range of 0.125 to 1 and n/(m+n) is in the range of 0 to 0.875 when the molecular weight of the polyoxyalkylene glycol is greater than 700 and m/(m+n) is in the range of 0 to 1 and n/(m+n) is in the range of 0 to 1 when the molecular weight of the polyoxyalkylene glycol is less than or equal to 700.

In said working fluid composition, preferably the amount of glycerol is in the range of from 1 to 95% by weight; the amount of alkylene glycol(s) is in the range of from 0 and 50% by weight; and the amount of polyoxyalkylene glycol(s) is in the range of from 0 to 90% by weight, all based on the total weight of the base fluid.

Preferably, said working fluid composition comprises base fluid in an amount in the range of from 50 to 100 % wt., based on the total amount of base fluid and diluent.

In the process of the present invention the base
fluid is reversibly diluted with the diluent in response
to a change in the system operating conditions. The
process further comprises a step in which a change in

5   operating condition is detected directly or indirectly,
e.g. by monitoring one or more properties of the
lubricant. The properties of the lubricant that are
monitored may be temperature, viscosity, composition,
traction, density and refractive index amongst others.

10   Removal or separation of the diluent from the base
fluid can be effected by means such as evaporation or
distillation. In one embodiment of the present
invention, energy generated by the system being
lubricated is utilised to provide at least part, and

15   preferably all, of the energy required in the separation
of the diluent from the base fluid. This has clear
benefits in the efficiency of the process of the present
invention.

The energy generated by the system may be, e.g.,

20   heat energy, mechanical energy or electrical energy. The
energy may be generated directly by the operating
components being lubricated or to which the working fluid
has been applied, e.g., heat energy. The energy may be
generated indirectly by the system, e.g., heat energy

25   produced by an engine which drives wheels through a
transmission or electricity produced by an electricity-
generating windmill which comprises a traction drive.

The present invention further provides apparatus
suitable for carrying out the process of the present

30   invention which apparatus comprises means for reversibly
diluting the base fluid with the diluent and means by
which energy generated by the system is utilised to
provide at least part of the energy required in the

separation of the diluent from the base fluid. The means
for reversibly diluting the base fluid with the diluent
include means for adding the diluent to the base fluid
and means for removing diluent from the base fluid.

5   The apparatus of the present invention may further
comprise:

(i)   reservoir means comprising a diluent;

(ii) a mixing zone comprising a base fluid;

(iii) dispensing means for supplying the diluent from the

10   reservoir means to the mixing zone;

(iv) separating means for removing diluent from the
        mixing zone; and

(v)   means enabling the contents of the mixing zone to
        contact an operating component of the system.

15   In an embodiment of the present invention, there is
provided an apparatus for carrying out the process of any
one of the preceding claims which comprises:

(i)   reservoir means comprising a diluent;

(ii) a mixing zone comprising a base fluid;

20 (iii) dispensing means for supplying the diluent from the
        reservoir means to the mixing zone;

(iv) separating means for removing diluent from the
        mixing zone; and

(v)   means by which energy generated during operation of

25   the system is utilised by the separating means to
        separate the diluent from the mixing zone.

      The mixing zone may be, e.g. the sump or main fluid
reservoir for a transmission or the main fluid reservoir
in a hydraulic system. The means enabling the contents

30 of the mixing zone to contact an operating component of

the system may comprise a series of pumps and an oil circuit.

The apparatus may also comprise means for monitoring a change in system operating conditions such as a programmable controller which may form part of a main engine management system. The programmable controller may be used to assess the current composition and properties of the mixture and to instigate the withdrawal or addition of diluent as required by the state or operating condition of the machine.

The apparatus of the present invention comprises means for separating the base fluid from the diluent. Separation may be effected by evaporation or distillation of the relatively volatile diluent from the mixture of

diluent and base fluid, optionally under reduced
pressure.   The separating means typically consists of a
device to perform flash distillation, vacuum distillation
or distillation of the mixture of base fluid and diluent.
Separation can be controlled to remove the diluent from
the mixture at the desired rate.   In one embodiment, the
lubricant or working fluid is pumped to the separator by
an oil pump, preferably the system's main oil pump, with
a proportion of the lubricant/working fluid flow being
passed through the separator.   This proportion is
variable from 0 to 100%.

In the separating means the incoming mixture is
heated to a temperature high enough to form an
appreciable vapour pressure of the relatively volatile
diluent.   The vapour and the depleted residual base
lubricant are separated, this may be achieved using a
pump.   The vapour can then be condensed and stored for
re-use and the residual base lubricant can be re-injected
into the lubricant circuit at some point, for example, at
the sump.

Energy may be required to heat the mixture to the
separation temperature and to evaporate the diluent. The
apparatus of the present invention further comprises
means by which energy generated by the system being
lubricated or to which the working fluid is applied is
utilised in the separation of the diluent from the base
fluid.   In one embodiment of the apparatus of the present
invention, the separator draws some of the heat required
for the separating step from the surplus heat rejected by
the engine that drives the machine.   Engines reject
excess heat into the coolant (water/antifreeze), into
exhaust gases, and into the engine lubricant.   Each of
these may be used as sources of heat for the separator.

In general the distillation step will operate by removing a small proportion of the liquid flowing through it. It follows that much of the heat put into the lubricant mixture to raise it to the distillation temperature, can

5   be recovered and used to heat the incoming flow of fresh mixture into the separator.

The separator may consist of one or several heat exchangers through which the incoming mixture passes in sequence before reaching the distillation chamber. These

10   heat exchangers are used to progressively raise the temperature of the incoming mixture, and can be used to lower the temperature of the depleted mixture after it has passed through the distillation or evaporation chamber. A typical sequence might pass the incoming base

15   fluid/diluent mixture through one or more of the following stages, each being identified in the list by the source of the heat that is used to raise the temperature of the incoming mixture:

(a)   Engine hot water stage, in which the incoming

20   mixture is heated, e.g. from the current sump temperature to approximately 85°C, by thermal contact with hot water from the engine cooling system. Such hot water is generally available after approximately a minute of engine operation. This heat exchanger can operate

25   passively until, e.g., the incoming mixture reaches 85°C, at which point the flow of water may be switched off.

(b)   Hot lubricant stage, in which the incoming mixture is heated by thermal contact with a stream of lubricant or working fluid that has passed through the evaporation

30   chamber.

(c)   Diluent vapour condensation stage, in which hot vapour from the distillation chamber is condensed,

realising the heat of vaporisation to the incoming
mixture.

(d)   Engine-exhaust heating stage, in which heat is
obtained, most probably by an indirect method, from the
hot exhaust gases. This stage might be combined with
stage (c), using vapour produced by boiling the diluent
in a tube around the exhaust pipe to transfer heat.

(e)   Electrical heating stage, most probably forming part
of the evaporating chamber, in which the input steam is
heated finally to the temperature at which the separation
by evaporation proceed at the desired rate.

     In one embodiment of the present invention, one of
more of the heating stages operate passively, with the
proviso that certain flows may be stopped by closing
valves at some temperatures. Furthermore, the optional
stage in (d) in which heat is transferred from the
exhaust by condensing vapour, can be designed so as to
stop automatically when the evaporation of the diluent
from the mixture is complete.

     The use of reduced pressure, that is a pump to move
the vapour that evaporates from the mixture, may form
part of the separator scheme. The vapour pump may be
mechanical, such as an axial or a turbine compressor, or
a vane pump, or a centrifugal pump; or alternatively it
may take the form of a vapour jet ejector pump, whose
application is described in more detail below. The
purpose of the pump is to enable the separation of vapour
and mixture to occur at a lower temperature. It is not
necessary that the pressure be reduced to a point at
which the mixture would boil. The purpose of the pump
would be to remove the vapour that is in equilibrium with
the mixture, so as to permit the evaporation of more
vapour.

If a vapour-jet ejector is used as the pump, the motive gas for the ejector could be the vapour of the compressed diluent itself. The compressed liquid would need to be heated to a temperature high enough to ensure that the vapour saturation pressure provides the necessary motive flow through the ejector. The heat for this could be obtained from the surplus heat of the engine. The flow of motive gas or vapour through the ejector would be combined with the 'suction flow' of vapour (of the same composition) coming out of the mixture. This jet of vapour would be condensed to liquid in a heat-exchanger, transferring the heat of the condensing vapour to one or both of two other liquid streams: the flow of diluent towards the high-pressure, high-temperature side of the vapour jet ejector, and the flow of oil/diluent mixture towards the separator.

The motive gas for the ejector could alternatively be steam which could be generated by using surplus heat from the engine or energy from another source. The steam combines with the suction flow of vapour in the diffusion zone of the ejector and both vapours are condensed so as to impart their heat usefully to other streams as described above. The condensed water and the diluent, if the latter is immiscible with water, can be separated and the diluent stored for re-use in the reservoir. In this case the water would not act as a lubricant and would not contact the lubricated surfaces. If the diluent is water no separation would be possible or necessary.

In yet another variant, vapour may be drawn from the environment of the lubricated machine part. For example, in the traction drive, the fluid is used to lubricate machine parts that are moving rapidly and imparting heat to the lubricant. It is anticipated that the movements

of the machine parts will create films and droplets of
lubricant so that the total surface area of the lubricant
will be large enough to facilitate rapid evaporation of
the diluent vapour. This vapour can be pumped away

5   continuously, separating droplets of the base fluid as
necessary. This approach is beneficial in avoiding the
development of flammable concentrations of vapour in the
spaces surrounding lubricated machine parts.

       The process of the present invention is illustrated

10   by the following examples.

Example 1

       In this example, the variation with temperature of
traction coefficient and viscosity of a lubricant
according to the present invention was investigated.

15   Viscosity measurements were made with a Rheolyst
cone-on-plate rheometer. Traction coefficients were
measured using a "Mini-Traction Machine" manufactured by
PCS Instruments Ltd of London. In this device, a
polished steel ball (3/4 inch diameter) is caused to

20   rotate against a polished steel ring which is also
rotated. The speeds of the ball and the ring are
controlled separately so that the ratio of the sliding
motion to rolling motion can be adjusted by the machine.
The pressure in the contact is adjusted by the load

25   applied to the arm that bears the rotating ball. The
ball and ring are immersed in the lubricant whose
temperature is controlled. Measurements were made at
different slide-to-roll ratios (SRR) and under different
applied loads. Most of the results quoted have been

30   obtained at 2.2 % SRR under loads that generated
pressures close to 1.125 GPa in the lubricated contact.
The remaining results were obtained at other values of
the slide to roll ratio. These were corrected to provide

an estimated value of the traction coefficient at 2.2 % SRR.

The base fluid used was a distillation cut of the product available under the trade designation "Techtrac M73" ex. Tekchem Corporation (1-13-31 Denenchoufu, Ohta-ku, Tokyo 145, Japan), such that the proportion of dimers was about 10% by weight of the mixture. By about in this context is meant +/- 3%. The proportion of dimers to other compounds in the mixture, was determined by gas chromatography using a flame-ionisation detector.

The diluent used was the solvent commercially available ex. Shell Chemicals in the USA under the trade designation "CYPAR-9", which predominantly contains methyl-substituted and ethyl-substituted cyclohexanes with 9 carbon atoms.

The viscosity and the traction coefficient of the base fluid were measured as a function of temperature. The results are shown in Table 1.

Table 1

Temperature/°C	Traction Coefficient	Viscosity/mPas
150	0.097[1]	5.0[*]
140	0.102[m]	6.5
130	0.106[2]	8.9[*]
120	0.109[2]	12.5
110	0.110[2]	18.6[*]
100	0.111[m]	29.3
90	0.109[2]	49.6[*]
80	0.104[2]	92.5
70	0.094[m]	195[*]
60		484
50		1500[*]
40		6272

[*] The viscosity at these temperatures was obtained by interpolation, using a Vogel expression fitted to the measurements made at other temperatures. The Vogel expression fitted the data closely above 40°C.

[m] Direct measurement

[1] Estimated

[2] Measured at 5 % SRR and corrected to 2.2%. To make the correction, the values were reduced slightly from those measured. The largest correction was 0.006.

As shown in Table 1, this lubricant possesses a high and nearly constant traction coefficient over much of the range of temperature of importance in the warm operating condition (70 to 150°C). Furthermore the traction coefficient declines steeply as the temperature falls below 60°C. The viscosity changes quite slowly in the

temperature range 100 to 150°C, but at lower temperatures
begins to increase rapidly and exceeds 6 Pas at 40°C and
43 Pas at 30°C. On inspection, this fluid can be seen to
be unacceptably viscous at room temperature.

5　　　　　The base fluid was then mixed with varying amounts
of the diluent. The traction coefficient and the
viscosity at varying temperatures of the resultant
mixtures were then measured. By tracing the traction
coefficient as a function of composition and temperature

10　　　it was established what mix of base fluid and diluent
would be optimum at each temperature. The results are
shown in Table 2.

Table 2

Temperature /°C	Traction Coefficient	Viscosity/mPas	Wt% diluent in mixture
100	0.111	18.6	1
90	0.109		1.9
80	0.108[M]	55[E]	4.3
65	0.106[M]	60[E]	9.6
55	0.102	54	14.2
45	0.097	36	19.4
30	0.095[M]	40[E]	27.5
0	0.094	51	36.6

15　　　[E] Estimated since no measurement available at precisely
these conditions.

[M] These are the minimum traction coefficients expected at
these conditions. No measurements were available at
precisely the correct conditions. These numbers are

20　　　measurements made at these temperatures but on
concentrations that are not quite optimum.

The results in Table 2 shows that the viscosity and
traction coefficient of a base fluid can be controlled by
progressively diluting a base fluid with a liquid
consisting predominantly of methyl-substituted
cyclohexanes. If no further dilution were made and the
composition shown at 0°C were retained to a temperature
of -40°C, the viscosity would increase to approximately
2.5 Pas. Such a viscosity is far lower than that
achieved by other traction fluids. In particular the
results show that the maximum traction coefficient can be
maintained at lower temperatures while simultaneously
keeping the viscosity under control. From these results
it can also be concluded that the above traction fluid
mixture is suitable for use in traction devices where the
operating temperature is expected to lie in the range of
70 to 150°C, where the lower temperature is the
temperature of the reservoir of the base fluid and
diluent mixture and the upper temperature is that
experienced in the track where one element of the
traction drive rolls over another so as to transmit the
torque.

Example 2

In this Example, it is shown how reversible dilution
can be used to maintain at a constant value, the
viscosity of a composition that could be used as a
hydraulic fluid. Either the viscosity at ambient
pressure, or the viscosity at an elevated pressure, may
be held constant over a range, and both may be held
within a much narrower range than would be possible in a
fluid of constant composition.

The film thickness formed by the liquid in an
elastohydrodynamic (EHD) lubricated contact can be

controlled within a narrow range simultaneously.
Hydraulic fluids are frequently required to act as
lubricants by forming a load-bearing film of liquid
between metal surfaces, that approach each other closely
5   but must be kept apart to avoid wear. Such requirements
for EHD lubrication may occur within the pumps that
supply fluid at elevated pressure to the hydraulic
actuators. In EHD lubrication, the thickness of the film
of liquid between two moving surfaces depends both on the
10   viscosity of the fluid at the intake to the lubricated
zone, and on the pressure-viscosity coefficient. The
pressure-viscosity coefficient describes the increase of
viscosity with pressure in the liquid, and may be defined
as the slope of a plot of the natural log of the
15   viscosity against pressure.

The pressure-viscosity coefficient of most liquids
decreases with temperature. In a lubricant of constant
composition, the load-bearing film has a strong tendency
to decrease with increasing temperature because both the
20   viscosity and the pressure-viscosity coefficient decrease
with rising temperature.

Viscosity measurements were made with a Rheolyst
cone-on-plate rheometer. Film-thickness measurements
were made in an optical ball-on-plate rheometer. In this
25   apparatus, a steel ball is cause to rotate and slide
against a rotating disk of transparent material. The oil
film thickness can be measured with the use of the
interference fringes formed in the fluid-filled gap
between the disk and the ball. The pressure-viscosity
30   coefficient can be estimated from the film thickness.

The base fluid used was a mixture of glycerol and
mono-propylene glycol (propane-1,2-diol). By varying the
relative proportions of these two fluids, the viscosity

at different temperatures can be selected. In this
Example, the base fluid was a mixture of 90% by weight
glycerol and 10% by weight mono-propylene glycol. A
mixture of this base fluid with water, in which the water
content of the final mixture is up to 40% by weight, has
a final melting point at or below -40° Celsius.

     For the purposes of this Example, the water content
of the mixture was restricted to the range 5 to 35% by
weight of the ternary mixture. That is to say, a
composition described as "35% water" consists of 35% by
weight of water mixed with 65% by weight of base fluid,
where the base fluid in turn was the 90/10 mixture
described above.

     The composition was held constant over the
temperature range from -40°C up to the target value at
which it is to be maintained constant. For the purpose
of this Example, the constant viscosity was selected be
30mPa.s. Viscosities higher or lower than 30mPa.s could
be selected for this or similar mixtures.

     In Table 3, the viscosity of the mixture with 35%
water is shown as a function of temperature from -40°C to
7.8°C, at which temperature the viscosity has fallen to
30mPa.s.

Table 3

Temperature (°C)	Viscosity (mPa.s)
-40	2300
-30	688
-20	246
-10	104
0	48.3
7.8	30.0

The viscosity (at ambient pressure) can be held constant at 30mPa.s by reducing the water content as the temperature rises. In this example, it has been assumed that the water content will not be reduced below 5% by
5   weight. In Table 4, the fluid composition that yields a viscosity of 30mPa.s is indicated at each temperature.

Table 4

Temperature (°C)	% water by weight, in a mixture with 90/10 base fluid
7.8	35.0
20	27.6
30	21.7
40	16.0
50	10.9
60	5.85
61.7	5.00

Thus, over the temperature range from 7.8 °C to 61.7 °C the ambient-pressure viscosity can be maintained constant at 30mPa.s by altering the composition according
10   to the scheme above. This may be called the region of control.

The values of the pressure-viscosity coefficients determined in fluids of different compositions within the
15   region of control, are presented in Table 5.

Table 5

Fluid Composition (wt % water in the mixture)	Pressure-viscosity coefficient, GPa^{-1}
35	3
25	3.5
15	4
5	6

These pressure-viscosity coefficients were calculated from measurements of film thickness using the Dowson-Hamrock equation,

$$h_c = k\alpha^{0.53}(U\eta_0)^{0.67}$$

Where h_c is the film thickness,

   k is an apparatus constant,

   α is the pressure-viscosity coefficient,

   U is the entrainment speed, and

   η_0 is the viscosity at ambient pressure.

Measurements of the film thickness in the four fluids of Table 5, were made at the temperatures at which each of these compositions would be employed if the ambient-pressure viscosity were to be held constant or nearly constant, at 30 mPas. The exception was the fluid containing 35% water. This composition is correct for a temperature of 7.8°C, but the film thickness was measured at room temperature because it was not possible to operate the apparatus at lower temperature. When allowance is made for this, it can be seen that the pressure-viscosity constant changes slowly across the region of control until the water content is low. The

pressure-viscosity coefficient (and the film thickness)
increases as the water content falls towards 5%.

It is possible to use the Dowson-Hamrock equation,
with the measured value for the parameters k and α and
measured values for the viscosity, to estimate the film
thickness at other temperatures and at conditions
slightly different from those of the measurements. A
value for the entrainment speed (1.13 ms^{-1}, where the log
of film thickness was increasing linearly with speed) was
selected from the range used in the measurements of film
thickness, for these calculations. Table 6 below
presents the results of such calculations, for the
viscosity at ambient pressure; the viscosity at an
assumed working pressure of 20 MPa; and for the film
thickness under the conditions of the measurement in the
ball-on-plate rheometer. The results fall into three
groups:

(1) At temperatures below 8.8°C, the composition
     was assumed to be constant at 35% water. The
     film thickness was estimated from the Dowson-
     Hamrock equation using the pressure-viscosity
     coefficient measured for this composition.

(2) At temperatures in the control region between
     8.8 and 64.5°C, it was assumed that the
     composition would change so as to allow the
     ambient viscosity to decline slightly, to the
     extent that the viscosity at the working
     pressure would remain constant at 30 mPas.
     Small adjustments to the measured film
     thicknesses were made to allow for the small
     changes to the assumed intake viscosities.

(3)   At temperatures above 64.5°C, the composition
        was assumed to be constant at 5% water, and
        film thicknesses were estimated from the
        Dowson-Hamrock equation using the pressure-
        viscosity coefficient measured for this
        composition.

Table 6

Temperature /°C	Viscosity/mPas at 0.1 MPa	Viscosity/mPas at 20 MPa	Film Thickness/ nm
-30	785	833	686
-20	247	262	316
-10	100	106	172
0	48	51	106
8.8	28.3	30	74
25.4	28	30	80
43.4	27.7	30	85
64.5	26.6	30	102
75	17.2	19.4	76
80	14.3	16	68
85	12	13.5	60
90	10.2	11.5	54

Note that the temperatures that define the ends of the
region of control, shift slightly when the viscosity is
held constant at elevated pressure rather than ambient
pressure.

If the fluid mixtures described in this Example were
to be used in conjunction with an apparatus to adjust the
composition over the region of control, the effective
viscosity would vary according to Table 6. The viscosity
could be maintained at a constant value between 8.8 and
64°C by varying the composition in accordance with the

process of this document. Above and below this region of control, the viscosity would vary normally. The change in composition also affects the pressure-viscosity response, so as to reduce or eliminate the tendency of

5   the oil film thickness under EHD conditions, to decrease. The load-bearing capacity of the fluid is thereby maintained. If no change in composition were made, the variation of viscosity of the base fluid would be unacceptably rapid for use in a hydraulic circuit exposed

10   to varying temperatures. It must be noted that the oil film thicknesses shown here are those found in the laboratory measurement apparatus and apply to that specific combination of materials, geometry and load. The oil film thickness in other bearings would be

15   different.

It will be evident that the use of different base fluids would enable the region of control to be established over different temperature ranges and at different viscosities. In this way, the mechanical and

20   volumetric efficiencies of a hydraulic system would be maintained at or close to their optimal level, over a range of temperature from cold start to the warm operating temperature.